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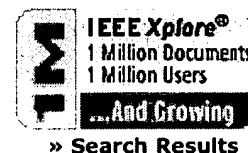
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# A recipe for Bayesian network driven fisheries stock assessment

T.R. Hammond, DRDC – Atlantic, 9 Grove Rd., Dartmouth, NS, Canada.  
Tim.Hammond@drdc-rddc.gc.ca

## Ingredients

- One personal computer, with at least 1 GB of random access memory
- Bayesian network software, see <http://www.ai.mit.edu/~murphyk/Bayes/bnsf.html> for different products, and see Jensen (1996) for an introduction
- Fisheries stock assessment data including time series of catch and survey catch rates

## The dish: Le stock assessment du Réverend

Bayesian fisheries stock assessment is effective at conveying uncertainty about stock status and at evaluating management options, but the most widely used algorithm, Markov Chain Monte Carlo (MCMC), is slow and can fail to converge. While convergence is tested by various diagnostics, these can only reveal failure, never success. Therefore, this paper suggests using Bayesian network propagation (BNP) to compute posterior results instead. Converting the continuous assessment model to a Bayesian network (BN) using Fuzzy Discretization makes this possible.

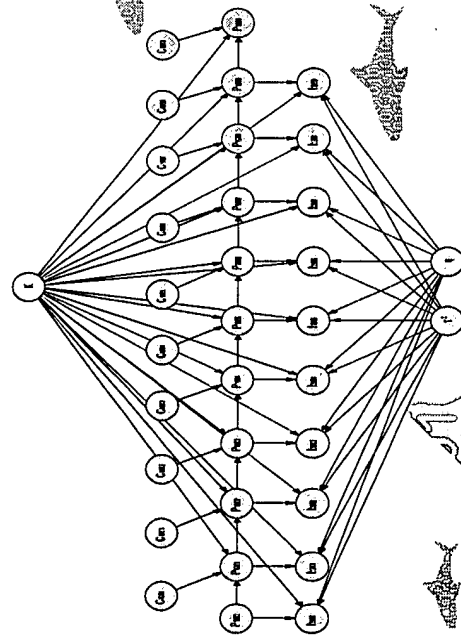


Figure 1: This is a Bayesian network in which random variables are represented with labelled bubbles. Complete specification of this Bayesian network involves defining a conditional probability table for each variable. The table for a particular variable must be defined given the states of any other variables that point to it with arrows. For example, the table for  $P(Y)$  would be conditional on  $P(X)$ ,  $P(Z)$ , and  $K$ .

## Directions

1. Draw the graphical representation of the assessment model, as in Figure 1
2. Convert continuous model equations and distributions to conditional probability tables (CPTs) using Fuzzy Discretization (see below)
3. Construct a BN from the results of 1 and 2
4. Introduce survey catch rates (or other data) as 'evidence' on the BN
5. Propagate the evidence with BNP
6. Refine the discretization of continuous variables and repeat 2-5, until the state grids of each variable align with the interval of high marginal posterior probability
7. Use the final BN to estimate quantities of interest, like the carrying capacity ( $K$ )

## Preparation Technique: Fuzzy Discretization

Fuzzy Discretization converts continuous equations and distributions into CPTs. While converting distributions is relatively straightforward, equations are trickier. For example, let random variables  $X$  and  $Y$  have states  $\{0, 1, 2, 3\}$  and let  $r.v. Z$  have states  $\{0, 2, 5\}$ . The object is to obtain a conditional probability table for  $Z$ , namely  $P(Z|X, Y)$ , from the equation  $Z = (X + Y)$ .

When  $X = 1$  and  $Y = 1$ ,  $Z$  should be in state 2, since  $1 + 1 = 2$ , so Fuzzy Discretization would assign probability one to  $Z$  being in state 2 and probability zero to states 0 and 5. Similarly, when  $X = 0$ ,  $Y = 0$ ,  $Z$  should then be in state 0 with probability one.

For other cases, the 'Fuzzy Result Rule' applies. When  $X = 1$  and  $Y = 2$ , for example, their sum is not a  $Z$  state. The two closest  $Z$  states are 2 and 5 and 3 is twice as far from 5 as it is from 2. Following this rule, Fuzzy Discretization would assign twice the probability to 2 that it assigns to 5 and other states would get nothing. When the exact answer falls between two states, the Fuzzy Result Rule partitions all the probability between them and the share assigned to each state is inversely proportional to the distance to the exact answer. If the exact answer falls outside the state grid, as it does when  $X = 3$  and  $Y = 3$ , all probability is assigned to the closest state, which would be 5. In general, compute the exact equation result, compare it to the states of the result  $r.v.$  and apply the 'Fuzzy Result Rule', as necessary.

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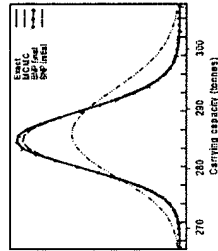


Figure 2: The marginal posterior density estimates for  $K$  from BNP and MCMC are compared to the exact answer, assuming  $q$  and  $t_2$  are known. The exact and BNP estimates are virtually indistinguishable by eye. The grid of  $K$  states is shown with a rug of tick marks along the horizontal axis. The initial BNP density estimate obtained before aligning the state grids with regions of high posterior probability is also shown, illustrating the dramatic performance improvement this entails.

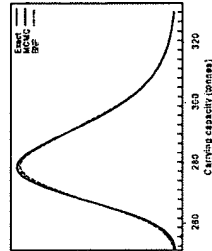


Figure 3: The marginal posterior density estimates for  $K$  from BNP and MCMC are compared to the exact answer.  $K$  and  $q$  were estimated but  $t_2$  was known. The  $K$  state grid is shown with a rug of tick marks along the horizontal axis.

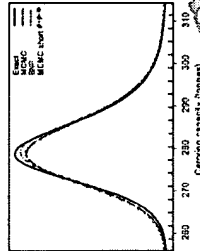


Figure 4: The marginal posterior density estimates for  $K$  from BNP and MCMC are compared to the exact answer when  $K$ ,  $q$ , and  $t_2$  are known. The BNP estimate is virtually indistinguishable from the MCMC estimate. The MCMC short-run results were obtained with only 250 000 iterations (as opposed to 500 000). These short-run results are virtually indistinguishable from the long-run ones.

## Performance

The technique was applied to the Schaefer assessment model of Meyer and Millar (1999), illustrated in Figure 1. Posterior density estimates for carrying capacity ( $K$ ) from both MCMC (as implemented in WinBUGS (<http://www.mrc-bsu.cam.ac.uk/bugs/welcome.shtml>) with 500 000 iterations, 20 000 burn-in, sampling every 500) and BNP were compared to exact results (obtained by analytic integration and grid-search) under three scenarios (Figures 2, 3, and 4). BNP outperformed MCMC in all scenarios, though the single-chain MCMC diagnostics in the BOA toolkit (<http://www.public-health.uowa.edu/boa/>) reported no problems.

While WinBUGS took over three hours to compute results in each figure, BNP took 3 seconds, 3 minutes, and 67 minutes to compute results in Figures 2, 3 and 4, respectively. BNP used a minimum of 25 states to discretize each continuous variable, and BNP run time is very sensitive to this number.

In summary, this recipe may provide a tasty alternative to MCMC for similar Bayesian problems.

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